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Linking power exhaust constraints with the Separatrix Operating Space through multi-machine (ITER, JET, SPARC) modelling and experiments

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Recent progress in describing the H-mode operational space and access to small-ELM regimes via the separatrix operating space (SepOS) framework highlights potential pathways towards viable integrated scenarios in next step devices like ITER and SPARC. However, remaining challenges in extrapolating integrated scenarios due to uncertainties in power width and impurity concentration scalings necessitate the need for connecting SepOS projections to power exhaust constraints defined by divertor target parameter specifications for tolerable PFC heat and particle loads. Quantifying the strong reduction in the separatrix density with increasing impurity concentration, as shown in the ITER divertor physics basis SOLPS projections [1], is of particular interest as it introduces another variable in the SepOS-power exhaust optimization.

In this work we focus on the interpretation of multi-device boundary plasma simulation datasets with the aim of framing dissipative divertor properties in terms of reduced dimensionality models that can be used to impose power exhaust constraints on the SepOS. We focus on exploiting observed self-similarities in SOLPS-ITER simulation datasets of ITER, JET and SPARC to inform experimental strategies in reactor-scale devices to safely map out the integrated scenario operational space. The strategy is underpinned by a strong dependence of divertor momentum and power losses on the target electron temperature, Te,t, describing a range of 'dissipation pathways'over a range of fueling, impurity seeding, heating power and cross-field diffusive transport assumptions. The variation in the momentum and power loss trends across the three devices constrains the achievable upstream parameters and thus the accessible dissipative SepOS. Within this framework, we quantify the reduction in upstream electron density, ne,sep, as a consequence of strong radiative losses in impurity seeded scenarios and contrast the numerical results against JET-ILW experiments which show significant (30-50%) ne,sep reductions in L-mode and H-mode high frad experiments. Lastly, using synthetic diagnostic techniques, we consider observables that satisfy reactor compatibility constraints while preserving the fidelity of the simulation output physics quantities, with emphasis on passive divertor spectroscopy.

[1] Pitts R.A. et al 2019, Physics basis for the first ITER tungsten divertor, Nuclear Materials and Energy 20 100696

Speaker's title

Mr

Speaker's Affiliation

Oak Ridge National Laboratory, Oak Ridge, TN

Member State or IGO

United States of America

Author: LOMANOWSKI, Bart (Oak Ridge National Laboratory)

Co-authors: PARK, J.-S.; LORE, J.D.; STANGEBY, P.C.; EICH, T.

Presenter: LOMANOWSKI, Bart (Oak Ridge National Laboratory)

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